2-D RANGE HOPPING SPREAD SPECTRUM ENCODER/DECODER SYSTEM FOR RF TAGS

Background of the Invention

Field of the Invention

[0001] This invention relates generally to coding techniques utilized in connection with spread spectrum radar systems and more particularly to a secure spread spectrum (SS) encoding technique which merges communication and radar technologies, whereby an airborne radar interrogates and receives pseudo noise coded messages from one or more ground based digital RF tags.

Description of Related Art

[0002] Spread spectrum is a well known modulation technique wherein a transmitted RF signal is spread over a wide frequency band and has particular applicability not only in communication systems, but also in the field of radar where there is a need for avoiding detection by countermeasure systems employed either on the ground or by other aircraft. This technique is typically utilized in connection with synthetic aperture radar (SAR) and ground mapping target indicator (GMTI).

[0003] Several general types of spread spectrum techniques are known. One type is known as direct sequence modulation and involves modulation of a carrier by a digital code sequence whose bit rate is much higher than the information signal bandwidth. The second type employs FM modulation called "chirp" wherein a carrier is swept over a wide band during a given pulse interval. The third type involves carrier shifting or hopping in discrete increments in accordance with a predetermined code sequence.

[0004] Thus in all cases, spread spectrum transmission thus involves expanding the bandwidth of an information signal, transmitting the expanded

signal, and then recovering the desired information signal by remapping the received spread spectrum original information signal's bandwidth.

Summary

[0005] It is an object of the present invention, therefore, to provide a hybrid communication technique which combines spread spectrum communications and radar pulse compression techniques in conjunction with digital RF tags, whereby a radar performing a surveillance mission e.g., SAR mapping additionally interrogates tags on friendly ground vehicles, which when interrogated by a downlink signal from the radar, sends back a very low level uplink message signal that appears noise-like so as not to degrade the primary surveillance mission, and to avoid enemy detection and exploitation.

[0006] This is achieved by retransmitting a phase shifted and time delayed version of the transmitted pulse from the radar. The digital RF tag captures every other pulse from the radar and transmits a digitally coded spread spectrum pulse back to the radar during every other intervening pulse which includes a pseudo random delay (range hop) and a pseudo random phase (angle). The uplink digital code comprises a coding structure which includes "soft symbol" message symbols consisting of n2 pulses preceded by a preamble (prefix symbol) of n1 pulses and terminated by a last (suffix) symbol consisting of n3 pulses, with the preamble and last symbols having sufficient signal to noise ratio to make initial and final detections by the radar. The message symbols are decoded in the radar by a sequential pruning of a hypothesis tree implemented with a series of matched filters. An important feature is that error correction code is built into the spread spectrum bandwidth expansion, rather than (or in addition to) applying an error correction code to information bits prior to spread spectrum bandwidth expansion. This provides a richer alphabet for the error correction code.

[0007] Further scope of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood, however, that the detailed description and specific example, while indicating the preferred embodiment of the invention, is given by way of

illustration only. Accordingly, various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

Brief Description of the Drawings

[0008] The present invention will become more fully understood from the detailed description provided hereinafter and the accompanying drawings, which are given by way of illustration, and thus are not limitative of the present invention, and wherein:

[0009] Figure 1 is a block diagram of an airborne radar system which communicates with a digital RF tag which receives a downlink radar signal and codes messages and data from a tag user and transmits the encoded data back to the radar in an uplink signal;

[0010] Figure 2 is a diagram of one tag message packet from the digital RF tag shown in Figure 1 to the radar in an uplink signal;

[0011] Figure 3 is illustrative of one symbol of an uplink tag message packet in accordance with a preferred embodiment of the subject invention;

[0012] Figure 4 is a diagram illustrative of one message symbol in an uplink tag message packet used in a related RF tag system;

[0013] Figure 5 is a block diagram illustrative of the details of the tag processor included in the digital RF tag shown in Figure 1;

[0014] Figure 6 is a block diagram of the details of the processor for the tag message included in the radar shown in Figure 1;

[0015] Figure 7 is a diagram depicting the generation of the range-Doppler map in the tag message processor shown in Figure 6;

[0016] Figure 8 is a diagram depicting phase align correlations for each detected tag message and running match filters for each hypothesized message; and

[0017] Figures 9A and 9B are illustrative of a sequence of pruning message symbols for detecting the message in the tag signal uplinked to the radar from the digital RF tag shown in Figure 1.

Detailed Description of the Invention

[0018] Referring now to the drawings wherein like reference numerals refer to like components throughout, reference will first be made to Figure 1 wherein there is shown a block diagram illustrative of the subject invention. Shown in Figure 1 is an airborne synthetic aperture radar (SAR) 10 which in addition to its normal radar mode is operable to transmit a downlink RF signal 12 to a ground based digital RF tag 14 located, for example, on a ground vehicle, not shown. Also shown is a tag user 16 consisting of, for example, apparatus used by a person on the ground vehicle wishing to communicate a message up to the radar 10. The tag user 16 generates a digital message which is fed to the tag 14. The tag 14, in turn, generates and transmits a digital pseudo noise coded RF uplink spread spectrum message signal 18 back to the radar 10. One tag 14 and tag user 16 are shown in Figure 1 for simplicity; however, there are generally multiple tags in a specific area of use governed by respective different users.

[0019] The radar 10 includes apparatus for generating and transmitting the downlink signal 12 and for receiving and responding to the uplink signal 18. The radar 10 is shown in Figure 1 including, among other things, a transmit/receive antenna 20 alternately coupled to an RF transmitter section 22 and an RF receiver section 24 by means of a circulator 26. The output of the receiver section 24 is connected to a radar processor section 28, which generates the necessary signals for displaying normal radar return data on a display 30. What is significant about the radar 10 is that it also includes a separate signal processor 32 for a tag message via the radar processor 28 included in the uplink message signal 18. The tag message signal processor 32 is also connected to the display 30 for displaying decoded messages and data from the tag 14. However, when desirable, the tag message signal processor 32 could be included in the radar processor 28 provided sufficient computational resources are available in the radar processor 28.

[0020] As further shown in Figure 1, the digital RF tag 14 also includes a transmit/receive antenna 34. The antenna 34 is connected by means of an RF switch 36 to either a receiver section 38 or a transmitter section 40. A local

oscillator 42 is shown connected to both the transmitter section and the receiver section 38 and 40. A digital RF memory (DRFM) and modulator 44 is located between the transmitter and receiver sections 38 and 40 and a digital signal processor 46.

[0021] Upon demand, the radar 10 illuminates the digital RF tag 14 with a downlink sequence of modulated pulses 12 which act to wake up one or more tags 14 as well as providing radar identification and uplink signal parameters and messages. The type of modulation used in the downlink is preferably pulsewidth modulation; however, the type of modulation could also be frequency modulation (FM), FM slope modulation (CHIRP) or a combination thereof. At least one of the illuminated digital RF tags 14 (Figure 1) captures, i.e. listens to, every other pulse from the radar 10 and responds by transmitting message data from the tag user 16 at every other intervening pulse. Alternatively, a chopper technique could be employed whereby listening takes place on parts of the pulse and transmitting takes place on other parts of the pulse; however, this results in a loss in signal, which would require less energy efficient transmission of the tag message.

[0022] The tag message in the uplink RF signal 18 is a code division multiple access (CDMA) signal, that is, multiple tags broadcast simultaneously, but they are "separated" in the sense that their codes are orthogonal. The tag messages are encoded as a coded pseudo random pulse sequence of delays and pseudo random phases so that it is covert under the cover of clutter. All tags look like noise to other tags and all transmit back to the radar 10 at the same time. In decoding any one tag, the effect of other tags transmitting to the radar is to raise the noise floor, i.e. increase the noise level. When the number of tags is less than a critical number, the raised noise floor is negligible; however, tags in excess of the critical number will start to degrade performance. The radar 10 detects the uplink pulse sequence 18 from the tag(s) 14, which is first de-chirped and motion compensated and then fed to the tag message processor 32 for message decoding, which will now be described.

[0023] Considering now the details of the coding and decoding technique associated with the uplink pulse sequence of a tag message, an underlying

premise to this approach is that if the total signal to noise ratio (SNR) per bit exceeds just slightly some level (Shannon's bound), then for extremely long messages, near perfect transmission can be achieved. If the total signal to ratio per bit is just slightly below this level, then no matter what the code, the probability of a transmission error is nearly one. If the SNR exceeds Shannon's bound, then Shannon showed that almost every random code book will achieve nearly perfect transmission.

[0024] Random codes have little structure, therefore they are complex. Accordingly, the coding structure in most instances must be highly complex. However, this implies that optimal decoding is also highly complex. Conventional turbo codes solve this problem by passing the information bits through a highly complex interleaver and concatenating the parity bits of a simple error code with another simple code on the original information bits (parallel concatenated, i.e. linked, codes). This allows for an almost optimal recursive decoding. The present invention, therefore, provides a complex code that enables trading off decoding complexity and energy efficient transmission, so as to enable near Shannon bound performance.

[0025] In the preferred embodiment of the subject invention, a pseudo-random noise code is generated such that each possible message corresponds to a different orthogonal code with a large integrated signal to noise ratio (SNR) so as to approach Shannon's bound and comprises a concatenation of "soft symbols" where hard decisions are not made at symbol boundaries, but rather hypotheses are pruned at symbol boundaries during decoding, meaning that the most unlikely hypothesis are weeded out at the symbol boundaries. These codes are generated using a pseudo-random noise generator 47 shown in Figure 5 with a common initial seed available at both the tag 14 and the radar 10 for enabling signal correlation. By making soft symbol boundaries where the channel coding branches out, a relatively simple sub-optimal algorithm is constructed which enables the pruning process. Also, as the integrated SNR increases with successive soft symbols, the delayed error in decoding prior symbols goes down dramatically. Consequently, with a slight margin in SNR over the Shannon bound, the number of likely hypotheses that needs to be

maintained becomes relatively small. The radar 10 arbitrarily sets the SNR via the down link signal 12 which also includes the parameters that controls the uplink signal 18 as shown, for example, in the following Table I.

TABLE I

Down Link Parameters For Tags	**Considerations**	**Parameter Range**
Prefix Symbol Scheme Choice	Dense environment can set for parity check to increase SS code distances. Sparse environment can set for improved tag detection/false alarm. Extreme case, one long common prefix coded with PN sequence of slopes and phases	Normally set To achieve 15 DB n1 pulses.
Sequence length for "Soft" Symbol, n2	Adjusted to desired SNR per symbol. Long range maps use longer sequences. Dense MAI environments may choose longer sequences. Longer sequences can also be chosen for reduced decoding computation.	10 to 100 pulses
Number of Valid delays (range hops) Per Pulse, Nhop	Larger number of hops improves performance with multiple tags in resolution cell at expense of greater processing.	100
Crypto Secure seed information	Serves to authenticate tag transmissions by making SS code dependent on initial random seed.	Already part of down link

[0026] Referring now to Figure 2, shown thereat is the basic coding structure of the message content of the uplink message signal 18 which includes spread spectrum pulse sequences having two degrees of freedom, i.e., range hopping and phase shifting, to achieve minimal mutual tag interference. It comprises a preamble 48 consisting of a sequence of n1 pulses 48_1 ... 48_n, a plurality of message symbols 50, each consisting of a sequence of n2 pulses 50_1 ... 50_n, and a suffix or final symbol 52 consisting of a sequence of n3 pulses 52_1 ... 52_n. Each of the n1, n2 and n3 pulses include at least one pseudo-random time delay or range hop 54 and a pseudo-random phase 56, as shown in Figure 3, with respect to a message symbol 50, which are used by the radar 10 to detect a tag's 14 location in range and Doppler from which angle can be derived.

[0027] In a related tag system, as shown in Figure 4, message symbols 50 consist of a sequence of n2 pulses including a pseudo random linear frequency change or "chirp" 55 and a pseudo-random phase 56. In the present invention,

time delays, i.e., range hops are used to prevent the tag from coherently integrating pulse-to-pulse unless the spread spectrum code is known and the message is correctly decoded. Thus, these are not used by the radar to "detect the tag", but rather used by the tag to make the tag look like noise for normal radar processing (i.e., not coherently add up). It represents an improvement over the related tag system in terms of decoding complexity since fast time (single pulse) matched filter processing can piggyback off the normal radar motion compensated and de-chirped signal.

[0028] Alternatively, when there are a reduced number of tags, multiple sums of replicated pulses each having a different range hop and phase, could be employed; however, each tag would have to communicate a larger message.

[0029] The n1 pulses of the preamble 52 have sufficient signal to noise ratio (SNR) to make an initial detection by the radar 10 which is used by decoding apparatus in the processor 32 to set up a trellis structure implemented by a set of matched filters 57_1 ... 57_n, as depicted in Figure 8A, which are mutually different for each path through the trellis.

[0030] The message symbols 50 comprise "soft symbol" message symbols generated by the tag user 16 (Figure 1) and their number depend on the message content the user 16 wants to send to the radar 10. The term "soft symbol" means that hard decisions are not required to be made at symbol boundaries as to the portion of the message presently being decoded, except that unlikely hypotheses are discarded in a pruning process of hypotheses. In the sequence of message symbols 50_1 ... 50_n, each succeeding message symbol 50_{i+1} depends upon the message content of the previous message symbol 50_i in accordance with the soft symbol coding technique whereby a convolutional code is generated capable of approaching Shannon's bound. If a mistake is made on a prior symbol 50, all further communication will look like random noise. Thus, by delaying decoding decisions, prior symbols can be decoded with arbitrary accuracy. Increased decoding accuracy is a tradeoff with computational complexity and tag signal strength.

[0031] The last symbol 52 consists of a sequence of n3 pulses having sufficient SNR to provide final message determination (parity).

[0032] Referring now to Figure 5, shown thereat is a block diagram of the details of the tag processor 46 (Figure 1) located in each RF tag 14 for generating a spread spectrum code for the soft symbols 50 shown in Figures 2 and 3. As shown, message symbols 50_1, 50_2 ...50_n generated in and supplied from the tag user 16 are fed to the spread spectrum code generator 47 which also receives a crypto secure seed look-up table 60 which is controlled by a clock 62 which is linked to the message processor 32 in the radar 10 so that a common initial seed is provided to both processors 32 and 36 for enabling signal correlation and to insure that if another radar would capture the radar's downlink 12 and rebroadcast it, the tag will be able to recognize that the attempted downlink/wakeup is not valid.

[0033] The code generator 47 comprises a computer program loop that separates the initial random seed progressively modified by the message intended by the user 16 into a plurality of code segments 64_0 ... 64_n comprising pseudo-random noise sequences (PRNS) of n1 pulses, n2 pulses and n3 pulses. The first code segments section 64_0 comprises a $PRNS_0$ sequence of n1 pulses for the preamble. The intermediate code segments 64_1 ... 64_2, for example, comprising $PRNS_1$ and $PRNS_2$ for the first two message symbols 50_1 and 50_2, while the last code segment 64_n comprises a last $PRNS_n$ sequence for generating the n3 pulses of the last symbol 52. As noted above, each pulse of the sequence of n1, n2, n3 of the preamble 48, the message symbols 50, and the last symbol 52, each include a pseudo random range hop 54 and a pseudo random phase change 56 shown, for example in Figure 3, which are sequentially applied to every other radar pulse received by the tag receiver 38 and captured by the digital RF memory (DRFM) and are transmitted back to the radar 10 by the modulator 44 by every other alternate, RF pulse of the uplink signal 18.

[0034] As noted earlier, the decoding process of the pseudo noise pulses transmitted from the tag 14 up to the radar via the uplink message signal 18 takes place in the processor for the tag message 32 shown in Figure 1. Reference is now made to Figure 6 where reference numeral 28 denotes the processor for the radar 10, which initially performs a fast time motion

compensated de-chirping of each received pulse followed by a range fast fourier transform (FFT) which provides tag return pulses in range plus delay plus pulse-to-pulse phase modulation which are then fed to the processor 32 for the tag message. A range Doppler map 68 is generated in slow time from n1 preamble pulses as shown by reference numeral 66 using the same crypto seed used by the tag processor 46 shown by reference numeral 60 to invert and align the pseudo random range hops and unwrap the phase shifts as shown in Figure 7. A clutter threshold 70 is applied to the range-Doppler map 68 in Figure 7 to obtain an initial estimate in range and Doppler (angle) for each detected tag as shown by reference numeral 72 in Figure 6. Once a tag 14 has been detected in range and Doppler, symbol correlation can be carried out in clutter as shown in Figure 8.

[0035] Next, as shown by reference numeral 74 in Figure 6, the n2 pulses for each message symbol $50_1 \ldots 50_n$ are used in a pruning or discarding process of hypothesis based on matched filter scores as shown in Figure 9A, whereat each soft symbol boundary, only two hypotheses paths having the highest "scores" of matched filter outputs are retained until the last message symbol 50_n is processed with a single score being retained as shown in Figure 9B. As shown in numeral 74 in Figure 6, the matched filter also provides a measurement that is used to update the Doppler tracker. The Doppler tracker uses the phase error from the matched filter to estimate Doppler drift. The Doppler estimate is also used to update the tag location in range. Thus, the mechanization allows relatively long integration times, since tag walk in range gates is prevented.

[0036] This is followed by processing the final n3 pulses of the last symbol 52 (Figure 2) so as to perform the final step of detection, whereupon the message data is fed and displayed on the radar display 30 shown in Figure 1.

[0037] Pruning of the soft symbol message symbols 50 are done based on matched filter estimated integrated signal-to-noise ratios over all currently maintained hypotheses. Pruning is performed by eliminating all but the top "nhypth" candidate messages at soft symbol message boundaries. This results in a side benefit of multiple tags in a resolution cell (range) Doppler showing up

as two hypotheses that persist throughout the decoding process, resulting in a greater probability of successful decoding of multiple tags in a resolution cell.

[0038] Thus what has been shown and described is a secure spread spectrum encoding technique where a radar, for example, performing a surveillance mission interrogates tags on friendly vehicles which in turn transmit a very low level signal back to the radar that appears noise-like so as not to degrade the primary surveillance mission and to avoid enemy detection and exploitation. The RF signal which is transmitted back to the radar from the RF tags consists of phase shifted, delayed versions of every other pulse transmitted from the radar.

[0039] The invention being thus described, it will be obvious that the same may be varied in numerous ways. Such variations are not meant to be regarded as a departure from the spirit and scope of the invention, and also such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.